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A PRELIMINARY REVIEW OF THE FLOW AND CHARACTERISTICS OF RECYCLED URANIUM THROUGHOUT THE DOE COMPLEX 1952 – 1999

PROJECT OVERVIEW AND FIELD SITE REPORTS

U.S. DEPARTMENT OF ENERGY
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1952 – 1999

PROJECT OVERVIEW

FIELD SITE REPORTS

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Summary

In August 1999, the Department of Energy (DOE) initiated a series of studies related to the Paducah Gaseous Diffusion Plant in order to address potential worker health effects from plant operations. One of these studies had significance to facilities across the DOE's nuclear complex, and focussed on determining whether radioactive fission products and transuranic elements—including technetium-99, plutonium, and neptunium-237—in the uranium feed or waste streams existed in sufficient concentrations to present a potential health or environmental concern. Trace amounts of the fission products and transuranic elements were contained in the recycled uranium, i.e., uranium that had been irradiated in a nuclear reactor, recovered through a separations process, and then sent to a gaseous diffusion plant for enrichment or to other locations for use. The presence of trace amounts of fission products and transuranic elements in the recycled uranium had little effect on the overall radioactivity of the recycled uranium. However, the potential for these materials to accumulate in various work stations at the Paducah plant were of concern to workers at the plant.

To address these issues, and promote the DOE's basic understanding of the flow and characteristics of this recycled uranium, the scope of the study was defined in September 1999 to include:

- Determine the mass flow of DOE recycled uranium from early production to mid-1999, including ultimate use and disposition; and create an unclassified inter-site flow sheet for public availability.

- Identify the characteristics and contaminants in the major uranium streams, specifically the technetium, neptunium, plutonium, or other isotopic content of concern to worker and public health and safety.

- Conduct site mass balance activities sufficiently thorough to identify any significant implications for potential personnel exposure or environmental contamination.

In response, major DOE sites initiated reviews, and dedicated teams were assembled to provide planning, direction, guidance, and coordination across the DOE complex. The site-specific reports issued with this overview reflect preliminary results – and also highlight one important area where more work will need to be done to provide the information required under the original scope of the study.

In particular, the preliminary results draw attention to the fact that, historically, there was no designated "recycled uranium" category in DOE records. As a result, each site developed operational definitions of recycled uranium to identify uranium flows of interest for this study. The site-specific definitions of recycled uranium vary depending on the specific processes and practices of the site. Because of these "definitional" differences among sites, and the manner in which each site designated recycled uranium, there is significant inconsistency and inherent uncertainty in the resulting data.

The flow of uranium among DOE sites and within various streams at individual sites was extremely complex. Processing sites used recycled uranium to create materials for reactor fuel and weapons components and shipped the materials to other DOE sites. Since processing normally required multiple steps and production optimization, the sites also interchanged materials among themselves. Operations within DOE frequently and deliberately concentrated the isotopes, diluted them, and blended them with natural uranium, in some cases increasing the total amount of uranium containing transuranics/fission products in the complex. Data on transuranics/fission product levels are incomplete; DOE did not track the trace quantities of transuranics and fission products other than ensuring plutonium concentration to be less than the 10 per billion specification.

Nonetheless, this review provides a broad understanding of the flow and characteristics of recycled uranium. The field reports describe the flow of recycled uranium from early production to its various uses and disposition.

Between March 1952 and March 1999, four production sites produced recycled uranium from spent nuclear fuel and targets at chemical separation plants, and shipped about 130,000 metric tons of uranium (MTU) to processing sites. Most of the production was complete by the late 1960s. Taking into account complex-wide inventories and the blending operations, it appears that there was more than 250,000 MTU of recycled uranium within the DOE complex.

The field reports identified a number of locations where the isotopes of interest could have concentrated or have been released, including the relevant historical periods, activities and concentrations. This information provides a starting point for identifying potential worker and public health and safety implications. The field reports also discuss the potential for occupational exposure at these locations, but the methodology used to determine this potential is subjective and does not reflect protection afforded by available radiological protection measures.

Based on process knowledge and analytical results, DOE has a good understanding of the characteristics and contaminants in the major recycled uranium streams and they are extremely low. However, attempts to construct a "mass balance" of contaminants was not successful due to the complexity of uranium flows among DOE facilities. DOE believes that development of a "mass balance" of contaminants is not practical with available records or of significant value for further studies. It is also DOE's opinion that further evaluation at individual DOE sites to identify any significant health implications are not required with the enactment of the Energy Employees Occupational Illness Compensation Program Act of 2000. Specifically, because of lack of reliable exposure data, workers at the gaseous diffusion plants do not have to demonstrate exposure to specific doses of radiation in order to receive benefits. The extensive environmental studies and remedial actions that DOE has on going at these twelve sites should identify and address any significant environmental implications for recycled uranium.

Due to different definitions of recycled uranium, DOE recognizes that there are uncertainties related to mass flow of recycled uranium among these twelve sites. Based on accountability data, DOE knows that there are no significant unexplained inventory differences in the production, processing, use and disposal of uranium. DOE tracks normal and depleted uranium as source nuclear materials, and enriched uranium, uranium-233 and uranium in cascades as special nuclear materials as a part of the materials control and accountability program. DOE plans to conduct follow-on assessments in the next two years to develop a historical mass balance for uranium, including recycled uranium.

1.0. Introduction

1.1 Background

In June 1999, workers at the Paducah Gaseous Diffusion Plant (GDP) raised concerns regarding the potential health effects of historic activities at the plant—particularly involving the processing of uranium. In response, the Department of Energy (DOE) initiated in August 1999 a series of studies related to the Paducah Gaseous Diffusion Plant to address potential worker health effects from past plant operations and review the status of current cleanup activities.

One of these studies had significance to facilities across the DOE's nuclear complex, and focussed on determining whether radioactive fission products and transuranic elements—including technetium-99, plutonium-239, and neptunium-237—in the uranium feed or waste streams existed in sufficient concentrations to present a potential health or environmental concern. These fission products and transuranic elements were contained in *recycled uranium*, i.e., uranium that had been irradiated in a nuclear reactor, subsequently recovered through a separations process, and then sent to a gaseous diffusion plant for enrichment or was blended with fresh uranium. The presence of fission products and transuranic elements in the recycled uranium had little effect on the overall radioactivity of the recycled uranium. However, the potential for these materials to accumulate in various work stations at the Paducah plant were of concern to workers at the plant.

In September 1999, the Office of Environment, Safety and Health (EH) was tasked with leading a study of recycled uranium used throughout the DOE complex over the last 50 years. The scope of the study was defined to include:

- Determine the mass flow of DOE recycled uranium from early production to mid-1999, including ultimate use and disposition; create an unclassified inter-site flow sheet for public availability.

- Identify the characteristics and contaminants in the major uranium streams, specifically technetium, neptunium, plutonium, or other isotopic content of concern to worker and public health and safety.

- Conduct site mass balance activities sufficiently thorough to identify any significant implication for potential personnel exposure or environmental implications.

- Conduct an occupational radiation exposure profile project at the three GDPs to characterize radiological conditions and the boundaries of occupational radiation exposures.

The goal was to summarize for public disclosure the flow and characteristics of recycled uranium from early production through its ultimate disposition, develop an unclassified inter-site flow sheet, and address any potential health risks presented by the material. Separate exposure assessments were to follow at three sites under a separate effort.

1.2 Approach

The assessment conducted to date was extremely complex. It involved a computerized search of millions of DOE records, the physical retrieval and review of several thousand of those records, and research and analysis of dozens of process sheets. Many people participated. Where historical records were not found or were inadequate, efforts were made to find people who may have had personal knowledge of events and practices. In cases where information now of interest was never compiled, best technical judgments were developed based on process knowledge.

Historically, there was no designated "recycled uranium" category in DOE records. As a result, general criteria were developed to identify material that could be generally designated as recycled uranium, and each site subsequently developed operational definitions of recycled uranium based on potential health effects to identify uranium flows of interest (see Appendix B). The site-specific definitions of recycled uranium vary depending on the specific processes, and practices of the site. Because of these "definitional" differences among sites, and the manner in which each site designated recycled uranium, there is significant inconsistency and inherent uncertainty in the resulting data. Federal staff and contractors were merged into a project-oriented team. A final Project Plan was issued in February 2000. A Headquarters Team provided overall planning, direction, guidance, and coordination. Dedicated Site Teams at each affected site conducted the study. A Working Group visited each site and independently reviewed the Site Team's work for accuracy and completeness.

Communication among the Site Teams and Headquarters Team was facilitated by weekly conference calls and periodic site visits. Two data exchange meetings took place to compare, exchange, and, where necessary, estimate missing information.

A report from each field site detailing the results of its analysis were used in preparation of this review. The reports are available on the Internet at http://tis.eh.doe.gov.

The field site reports identified a number of locations where the isotopes of interest could have concentrated or have been released, including the relevant historical periods, activities and concentrations. This data may be useful for identifying personnel exposure or environmental implications. The site reports also discuss the potential for occupational exposure at these locations, using a subjective evaluation of the following factors:

(1) the likelihood of material to become airborne;

(2) potential levels of specific radioactive isotopes; and

(3) the potential duration of occupational exposures.

However, the methodology used to determine this potential is subjective, and does not factor in engineering controls, protective equipment and measures, or the results of exposure monitoring.

1.3 Scope and assumptions

The assessment conducted to date tracks the general flow of recycled uranium—how much was produced and shipped in the DOE complex, and where it went. It also characterizes the recycled uranium in terms of three isotopes of interest—plutonium, neptunium-237, and technetium-99.

The major facilities that produced and processed recycled uranium were categorized as follows:

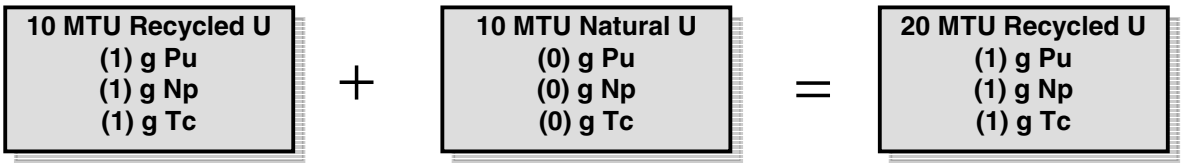
- **Production sites**—Chemical separation plants at the following four sites produced all recycled uranium that was used in the DOE complex: the Hanford Site, Washington; the Idaho National Engineering and Environmental Laboratory, Idaho; the Savannah River Site, South Carolina; and the West Valley Demonstration Project, New York.

- **Major processing sites**—Eight major sites processed most of the recycled uranium from the chemical separation plants: the Paducah GDP, Kentucky; the Oak Ridge GDP, Tennessee; the Portsmouth GDP, Ohio; the Feed Materials Production Center at Fernald, Ohio; the Oak Ridge Y-12

Complex, Tennessee; the Rocky Flats Plant, Colorado; the Weldon Spring Site Remedial Action Project, Missouri; and Reactive Metals, Inc., Ohio.

For the purpose of this review, the amount (weight) of the isotopes in recycled uranium introduced into the DOE complex is the amount received by the major processing sites from the chemical separation plants. However, the total amount of recycled uranium handled in the DOE complex is not fixed at the amounts the chemical separation plants produced; it is greater because the recycled uranium was deliberately blended as it flowed through the DOE complex. Because of this blending, the isotopes would become less concentrated (Figure 1 below) as the amount of recycled uranium increased[1], but the total amount of the isotopes introduced by the chemical separation plants would remain the same.

Figure 1. Blending (diluting) recycled uranium with natural uranium increases the amount of recycled uranium and decreases the concentration of the isotopes of interest; however, the amount of the isotopes (weight) remains the same.



1.4 Data limitations and caveats

The accuracy and completeness of the estimates used in this study depended upon the historical data available—the difficulties in obtaining accurate/consistent data from site to site was not anticipated when the study was initiated in 1999. Owing to practical fiscal and procedural constraints (including the significant volume of records to be searched, and the lack of easily accessible filing systems), especially at the Paducah GDP, all archived historical records could not be inspected. Where time and resources allowed, efforts were made to use cross-site information to generate and validate the missing data.

There was no designated "recycled uranium" category in DOE records. As a result, historical records do not differentiate between recycled uranium and other uranium. During this project, each of the sites made this differentiation for the uranium streams handled at their site. Because of differences between sites, and the manner in which each site designated recycled uranium, there is significant inconsistency and inherent uncertainty in the data developed for this study.

Material Control and Accountability (MC&A) records are designed to accurately account for inventories and transactions of uranium. However, the methods used in this study to designate "recycled uranium" limit the usefulness of these records. Therefore, total recycled uranium values used in this report are rounded to the nearest thousands of a metric ton of uranium (MTU).

Over the 50-year period covered by this report, chemical separation plants and processing sites typically analyzed and reported on isotope concentrations of shipments according to administrative guidelines in place at the time. Often, concentration limits were reported as "meets specifications" or "contains less than 10 ppb" to demonstrate compliance with requirements. This type of reporting required the field site reports to use calculated values and estimates to supplement historical data. The accuracy of the isotope concentration values is limited by the analytical uncertainty for a given analysis and the uncertainty of estimates made for missing data. The weights of the isotopes of interest were derived

[1] Note, however, that at some point the amount of dilution causes the uranium to fall below the threshold (or *de minimis*) level for it to be counted as recycled uranium; see discussion in Section 2.2.

from the estimated isotope concentration multiplied by the estimated mass flow value. As a result, the isotope weight values summarized in site reports have limited accuracy, and values for total isotopes were reported differently.

The amount of plutonium produced and received was carefully controlled and documented, however, data representing the trace isotopes contained in the recycled uranium was less accurate. Plutonium data are reasonably good at sites, for it was a desired product and recovery was important. Data on neptunium for the years prior to 1969 are sparse. Technetium was not measured as a constituent of recycled uranium until 1957, when Paducah began to identify it in the enriched product. The concentrations of technetium were typically based on statistically developed estimates of the distribution rather than analysis.

Because some sites, such as Fernald, had more data than others, two data exchange meetings were held to clarify information. Of particular concern was the limited data, particularly on neptunium and technetium. These meetings facilitated interaction among the sites in an effort to characterize the flow of recycled uranium and its constituent isotopes using available data. Data voids and differences were identified as the sites shared and validated available quantitative information (i.e., means and ranges for the plutonium, neptunium, and technetium). Ultimately, the team working on the field site reports agreed on estimates of site-specific quantities of recycled uranium and the constituent isotopes of interest.

1.5 Related actions

This recycled uranium project is one of five actions initiated by the Department in September 1999, responding to concerns raised by Paducah workers. These five actions are:

- Expanded medical surveillance of current and former workers.
- Investigated environment, safety and health (ES&H) concerns at GDPs at Paducah, KY; Portsmouth, OH; and Oak Ridge, TN.
- Supported an assessment of worker exposure to radioactive materials at the Paducah GDP.
- Reviewed options for compensating workers for occupational illness.
- Initiated DOE-wide studies of recycled uranium.

Expanded Medical Surveillance: As a result of health concerns at the GDPs, an ongoing medical surveillance program—which evaluated the health of former workers at risk of disease resulting from hazardous workplace exposures—was expanded in 1999 to include both current and former workers at the GDPs. The program currently is managed by a consortium of unions and universities and is now underway at 10 sites. Medical exams for 4,500 former DOE workers have been completed to date, and the program will be expanded to other sites in the upcoming year. The program at the GDPs also includes special screening for lung cancer.

Investigations of ES&H Concerns: Beginning in 1999, DOE conducted comprehensive investigations to examine historic ES&H practices at the GDPs, including protection for workers exposed to recycled uranium. The scope of the investigations was nearly unprecedented—over 1,000 workers and managers were interviewed; tens of thousands of records examined, and dozens of soil and water samples analyzed. The investigations revealed that a climate of secrecy and urgency to produce nuclear

weapons often took precedence over ES&H. Partly as a result of these investigations, the government acknowledged for the first time that workers who became ill because of these past safety practices should be compensated. The results of the investigations are available on the Internet at http://www.eh.doe.gov/oversight.

Paducah GDP Exposure Assessment: DOE conducted a study of Paducah GDP workers to determine if they may have had increased potential for radiation exposure, the locations and processes where increased exposure may have occurred, and estimates of exposure. DOE estimates that 2,500 to 4,000 workers worked in areas considered "moderate" to "high" for increased internal and external radiation exposures. Protective equipment was not always properly used. There were reports that contamination found on worker's personal clothing was above release limits. The January 2001 report, *Exposure Assessment Project at the Paducah Gaseous Diffusion Plant,* is available at http://www.eh.doe.gov.

Occupational Illness Compensation: When concerns from Paducah arose in 1999, DOE committed to look at how workers who were made ill from occupational illnesses could be compensated. Based on the ES&H investigations and the other efforts discussed above, Congress passed a landmark legislation (the Energy Employees Occupational Illness Compensation Program Act of 2000) that created a $1.6 billion entitlement program to help workers who develop certain cancers and lung diseases. The program is administered by the Labor Department. Because of the lack of reliable exposure data, workers at the GDPs do not have to demonstrate exposure to specific radiation doses in order to receive benefits. A new DOE Advocacy Office provides information and assistance to workers in filing federal compensation claims or state claims for illnesses not covered under the federal program.

2.0. Recycled Uranium Flow

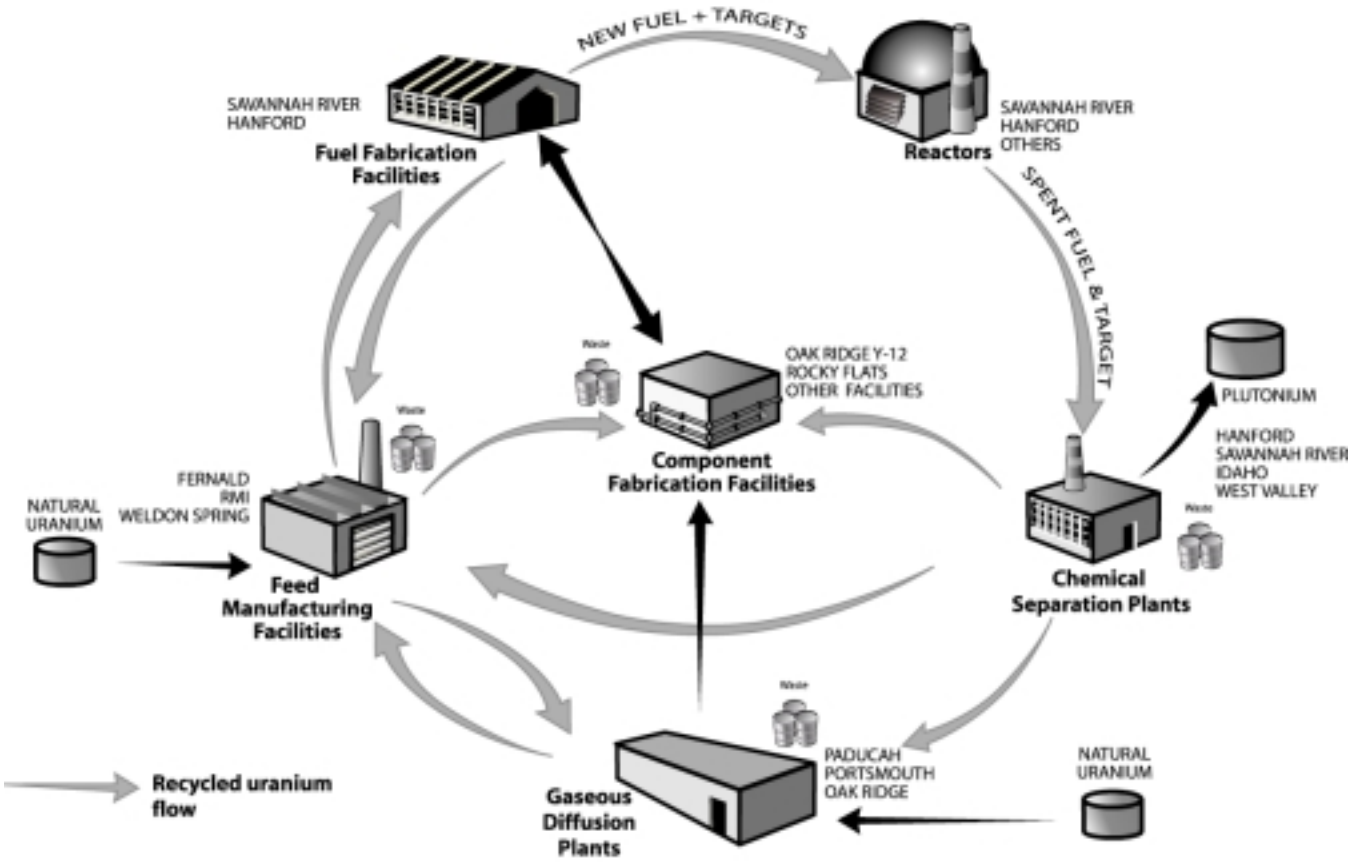
2.1 Simplified flow cycle

Presented as Figure 2 is a simplified illustration of the flow of recycled uranium throughout the DOE complex. The field site reports describe the cycle and the particular processes at each site in greater detail. In this figure, recycled uranium flow is shown by gray arrows. As indicated, spent nuclear fuel and targets were shipped from the reactors (at Savannah River, Hanford, and other sites) to the chemical separation plants at Hanford, Savannah River, Idaho, and West Valley (a site operated by a private company). West Valley also received spent fuel from non-DOE sources.

At the chemical separation plants, the spent nuclear fuel and targets were dissolved; then, by precipitation or extraction processes, plutonium (product) and uranium were separated, concentrated, and recovered. Most of the fission products and other transuranic isotopes were disposed of as high-level waste; however, trace concentrations of the isotopes of interest—plutonium, neptunium-237, and technetium-99—remained with the recovered uranium. From the chemical separation plants, the recycled uranium flowed to three principal types of processing facilities: the GDPs, the feed manufacturing facilities, and the component fabrication facilities.

At the three GDPs—Paducah, Portsmouth, and Oak Ridge—most of the transuranic isotopes were stripped from the recycled uranium and concentrated/diluted in the various processes prior the recycled uranium being fed to the enrichment process. In the enrichment process, recycled uranium with low levels of transuranic isotopes and fission products was blended with natural uranium, the predominant feed to the enrichment process, and was enriched to product assay levels for the weapons program, reactor fuel, and other uses. Recycled uranium containing concentrated levels of the isotopes of interest—derived primarily from the tower ash (i.e., by-products from the feed manufacturing process) at the Oak Ridge and Paducah GDPs—was processed or blended at Fernald to recover the uranium.

Figure 2. Simplified recycled uranium flow.



The feed manufacturing facilities, such as Fernald, processed recycled uranium either to final product or to feed material for the fuel/target fabrication facilities at Savannah River and Hanford. The deliberate blending of new and recycled uranium at the feed manufacturing facilities to obtain specific isotopic concentrations caused significant dilution of the isotopes of interest, but increased the amount of recycled uranium that flowed through the complex.

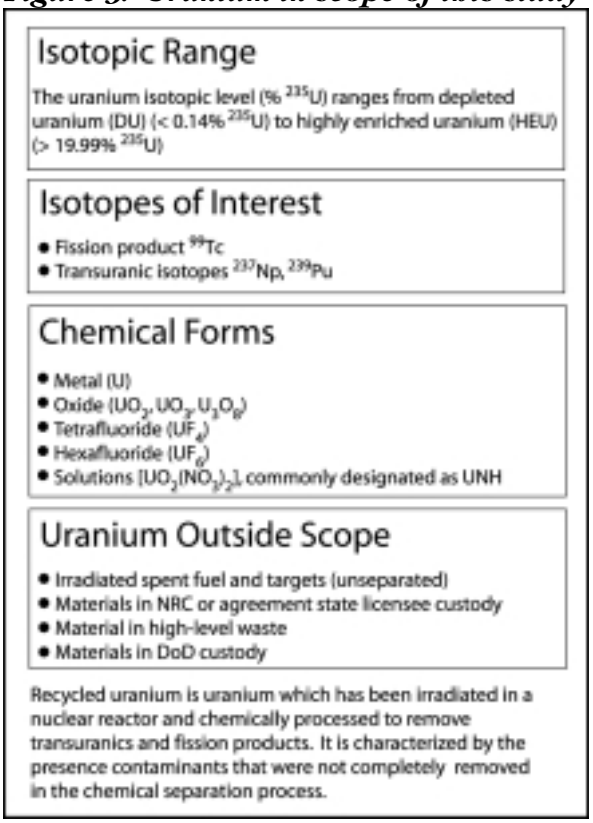
As illustrated in Figure 2, the manner in which recycled uranium flowed throughout DOE inevitably led to its becoming mixed with natural uranium and recycled uranium from multiple sources. In most instances this was done deliberately in order to adjust isotopic ratios. This blending, mixing, scrap recovery and redistribution, along with the use of the same process equipment for both recycled and natural uranium, led to the spread of the isotopes of interest in this study. Of critical note, it also made the recycled uranium difficult to track, and contributed to the inherent uncertainty of this study.

2.2 Recycled uranium considered within scope of preliminary assessment

Since there was no designated "recycled uranium" category in DOE records before this study, the Working Group developed criteria for determining when uranium falls within the scope of the study (see Figure 3 and Appendix B). The Working Group concluded that uranium was considered within the scope of the study if the isotopes of interest in uranium stream contributed more than 10 percent of the dose of uranium from natural sources (i.e., uranium that had not been exposed in a reactor).

The uranium was also considered "in scope" when (1) it contains sufficient uranium-236 to contribute more than 10 percent of the potential inhalation dose of the equivalent enrichment uranium made solely from natural sources[2], or (2) the chemical forms of the stream are such that further processing could concentrate the isotopes of interest to exceed the 10 percent criterion. Generally, uranium oxides, tetrafluoride and process residues are considered likely to be further processed. These criteria are consistent with current and historical technical views on recycled uranium, and provided a working definition of recycled uranium for the study. Absent such criteria, any uranium with a few atoms of transuranics more than those gained by spontaneous fission and neutron capture would be in scope.

Figure 3. Uranium in scope of this study



Using the 10-percent criteria, each site established its own operational definition of the recycled uranium flows that are in scope. Because of these different definitions, there is inherent uncertainty in this study. However, the sites applied their operational definition in a conservative manner; consequently uranium that may not contain significant levels of the isotopes of interest was included in the scope of the study. In general:

- All uranium flows from the chemical separation plants to the processing facilities were considered recycled uranium.
- Residual material from the gaseous diffusion feed plant processes was considered recycled uranium except for Portsmouth where no recycled uranium was processed through the feed plant.
- Product of the GDP cascades was not considered recycled, because the extensive constituent removal, processing, and blending would have reduced isotopes of interest to insignificant levels.

The operational definitions used by the various sites are presented as Table 1.

Table 1. Site-specific operational definitions of recycled uranium

Site	Operational Definition of Recycled Uranium
Hanford	All uranium handled, received, shipped, or stored after mid-1952.
Savannah River	All metal receipts from Fernald after 1961; all UO_3 and UNH receipts after 1954; and all shipments from the chemical separation plants.
Idaho, West Valley	All UNH and UO_3 from chemical separation plants. Receipts are out of scope.
Oak Ridge, Portsmouth, and Paducah GDPs	Data based on analysis. All receipts from chemical separation plants. All cylinders with recycle uranium heels. Cascade product is NOT recycled.
Fernald, RMI, Weldon Spring	All uranium after 1962. Compounds that could have been concentrated above the 10% criteria.

Key: UO3 uranium trioxide; UNH, uranyl nitrate hexahydrate; RMI, Reactive Metals Incorporated.

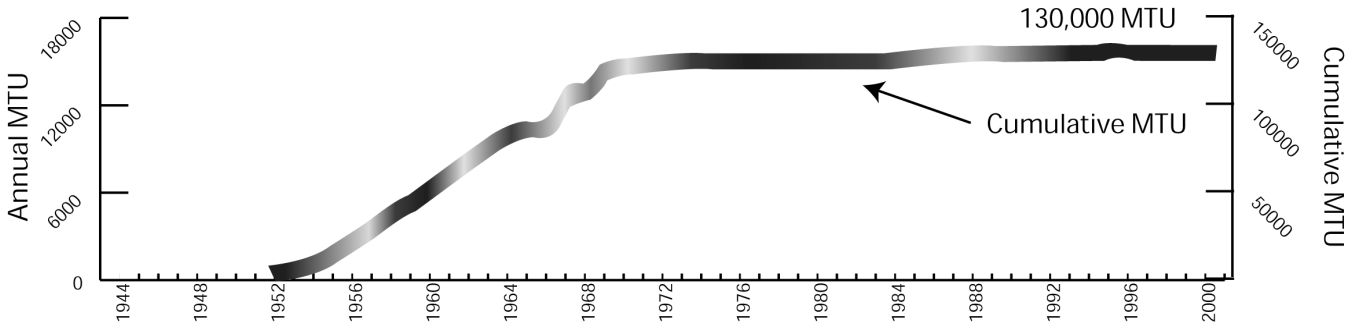
[2] Uranium-236 is discussed in the Savannah River, Oak Ridge Y-12 Complex, and Idaho Field Site Reports.

3.0. Recycled Uranium Production

3.1 Overall chemical separation plant shipments and total recycled uranium

Overall chemical separation plant shipments of recycled uranium are presented as Figure 4. In general, from March 1952 until March 1999, approximately 130,000 MTU was shipped from the four chemical separation sites. Most production was completed by the late 1960s. Taking into account complex-wide inventories and the blending operations, it appears that there was more than 250,000 MTU total recycled uranium in the DOE complex. These estimates will be reviewed and refined – and will likely change – as a result of a DOE follow-on study (discussed in section 4.0).

Figure 4. Overall shipments of recycled uranium from the chemical separation plants, 1952–1999.



3.2 Individual site summaries

Uranium was scarce relative to demand when its use for national defense began more than 50 years ago. With advancement in technology and ramping up of the Cold War, the United States in 1952 started at the Hanford Site to recover uranium from spent fuel and previously discarded high-level radioactive waste for reuse. Uranium that has been irradiated in reactors contains transuranic elements (e.g., plutonium and neptunium-237), fission products (e.g., technetium-99), and activation products (e.g., uranium-236). Following chemical processing to extract various isotopes of plutonium and to recover uranium for reuse, trace quantities of plutonium, neptunium, uranium-236 (mainly in the enriched portion of the product stream) and technectium-99 remain in the recycled uranium. These contaminants were introduced into the uranium cycle when recycled uranium was processed at the gaseous diffusion plants and feed material production plants. Recycled uranium was later introduced into the uranium cycle from the Savannah River Site, Idaho Chemical Processing Plant and West Valley Demonstration Project.

The site reports contain detailed descriptions of recycled uranium flows and the estimated amounts of trace contaminants in the recycled uranium. As stated earlier, due to the use of different definitions of recycled uranium among sites and complexity of the uranium operations, the estimated shipments and receipts among sites can not be simply added to develop a mass flow of recycled uranium.

A summary of the history and processes of the twelve primary recycled uranium sites is as follows:

- The **Hanford Engineering Works** (now known as the Hanford Site) was established during World War II to produce plutonium for national defense. The Hanford Site is located in southeastern Washington, near the cities of Richland and Yakima. During its operating period, 1943 through 1993, the U.S. government built and operated nine production reactors, five chemical separation plants, several reactor fuel manufacturing facilities, uranium trioxide production facility and several plutonium processing facilities. Hanford received uranium metal, mainly from Fernald, for

fabrication as reactor fuel for production of plutonium. Uranium recovery operations started in 1952 and recovered uranium was prepared into uranium trioxide powder for sampling and shipment offsite. Hanford shipped recycled uranium, mainly as uranium trioxide; the majority of the shipments went to the Paducah GDP. The Hanford Site is currently one of the largest clean-up operations in the world. Spent fuel is being moved from storage basins along the Columbia River to dry storage containers for storage away from the river. Plutonium in the Plutonium Finishing Plant is being stabilized and packaged for long-term storage, pending disposition. Safety issues associated with storage of high-level radioactive waste in underground storage tanks have been mostly resolved and waste is being prepared for vitrification and disposal. Deactivation of contaminated facilities and soil remediation is ongoing.

- The **Savannah River Site** is located in South Carolina along the Savannah River. Previously known as the Savannah River Plant, the Site operated one fuel and target manufacturing facility, five production reactors, two chemical separation areas and various waste management facilities from 1952 to produce tritium and plutonium for national defense. Plutonium production for national defense terminated in 1989. Savannah River Site received uranium metal, mainly from Fernald, and shipped uranium, mainly as uranium trioxide, with the majority to the Oak Ridge and Paducah GPD's and Fernald. Savannah River Site continues to operate its two chemical separation areas to stabilize at-risk nuclear materials for long-term storage and disposition. Savannah River Site is also the selected site for locating the Pits Disassembly and Conversion Facility and the Plutonium Immobilization Facility, as a part of a bilateral agreement with Russia to disposition weapons-usable nuclear materials. The Defense Waste Processing Facility is vitrifying high-level radioactive waste for storage and disposal at an off-site geologic repository. Other waste management functions, deactivation of contaminated facilities and soil remediation are all on going.

- The **West Valley Demonstration Project** is located in Cattaraugus County approximately 35 miles south of Buffalo, New York. The West Valley Demonstration Project, formerly referred to as the Nuclear Fuel Services West Valley Facility, operated as a private spent nuclear fuel reprocessing center from 1965 through 1972 using the Plutonium Uranium Extraction process. Throughout its operational history, West Valley received both commercial and government spent fuels, with roughly 60 percent of the fuel and 33 percent of the plutonium coming from DOE reactors. As a spent fuel processing facility, West Valley Demonstration Project is a source site and, therefore, did not receive recycled uranium. It did however, reprocess and recover recycled uranium and ship the recovered uranium to Fernald for conversion into metal and intermediate uranium compounds. Since the passage of the West Valley Demonstration Project Act (WVDPA) in 1980, the DOE and its site contractors have been involved in the solidification of high level radioactive wastes and the decontamination and decommissioning of the facility.

- Recycled uranium was produced at the **Idaho Chemical Processing Plant** where highly enriched uranium was recovered from spent fuel. The Idaho Chemical Processing Plant is located at the Idaho National Engineering and Environmental Laboratory (INEEL), previously known as the Idaho National Engineering Laboratory, in southeastern Idaho, near Idaho Falls. INEEL has been in operation since 1949 to test prototype reactors, perform reactor experiments, recover highly enriched uranium from spent fuel, and manufacture depleted uranium shapes for government purposes at the Specific Manufacturing Facility (SMC). Shipments from ICPP began in 1953 and continued until 1998. During this time period, highly enriched uranium was recovered from spent fuel, with a majority of the product shipped to the Y-12 Complex. SMC has received one lot of depleted uranium from Fernald and shipped shaped products offsite. The INEEL continues to manage spent fuel and perform waste management, environmental remediation and technology development activities; however, the chemical processing facility has been deactivated.

- The **Oak Ridge Gaseous Diffusion Plant** is located at Oak Ridge, Tennessee. Oak Ridge GDP, originally identified as the K-25 Site, started operations in 1945 as a part of the Manhattan Engineering District, was placed in stand-by status in 1985, and shutdown in 1987. The GDP was the first of the three United States gaseous diffusion plants. As part of the three plant complex, Oak Ridge GDP produced enriched uranium primarily for national defense purposes through 1964, and fuel for power reactors from 1965 through 1985. The plant began processing recycled uranium in 1952. Various oxides and scrap recycled uranium were processed and used as feed to the gaseous diffusion plants. DOE is in the process of decontaminating and decommissioning K-25, and has established it as the East Tennessee Technology Park (ETTP) for commercial uses of some of the cleaned up facilities.

- The **Paducah Gaseous Diffusion Plant** is located near Paducah, Kentucky and has facilities to convert uranium oxides to uranium hexafluoride and produce low enrichment uranium and depleted uranium. Paducah GDP processed recycled uranium intermittently from initial startup in 1953 through 1989. It received recycled uranium, mainly as oxides from Hanford, Savannah River, and K-25, and shipped recycled uranium, mainly as uranium hexafluoride to other gaseous diffusion plants, Fernald and commercial users. The gaseous diffusion process removed transuranics from the uranium hexafluoride and neptunium was recovered for use in other DOE programs. Paducah GDP is now leased to the United States Enrichment Corporation and continues to operate to produce slightly enriched uranium for commercial purposes.

- The **Portsmouth Gaseous Diffusion Plant** is located near Piketon, Ohio. The cascades at Portsmouth GDP can produce uranium at various enrichments, including highly enriched uranium (HEU). Portsmouth operated from 1955 and it is now leased to the United States Enrichment Corporation. It received recycled uranium, mainly as uranium hexafluoride from Paducah and shipped offsite, mainly to Fernald as uranium oxide. In 1991, DOE suspended HEU production. United States Enrichment Corporation recently announced that it is placing Portsmouth Gaseous Diffusion Plant on cold stand-by starting in mid-2001.

- The **Weldon Spring Site Remedial Action Project** consists of approximately 205 acres and is located in St. Charles County, Missouri. The Weldon Spring Site Remedial Action Project originally was operated by the Mallinckrodt Chemical Works as a feed materials plant for processing uranium and thorium ore concentrates, similar to the processes at Fernald. During operations, the plant processed uranium metal, intermediate forms including uranium dioxide, uranium trioxide and uranium tetrafluoride. Weldon Spring received and shipped recycled uranium, mainly dealing with Fernald, during its operating history. The facility was shut down in 1968 and has completed extensive remediation including the establishment of an onsite disposal facility since being placed on the National Priority List in the late 1980's.

- The **Fernald Environmental Management Project** is located in southwestern Ohio, near the communities of Fernald, Miamitown and Ross. The Fernald Environmental Management Project was formerly known as the Feed Materials Production Center. Production operations were active from 1952 through 1989. During this period, Fernald supported the national defense missions at Hanford, Savannah River, Oak Ridge Y-12 Plant, and Rocky Flats by producing various uranium products at standard enrichment assays. The Fernald Environmental Management Project was built by the United States Atomic Energy Commission (AEC) to establish an in-house integrated production complex for processing uranium and its compounds from natural uranium ore concentrates and recycled uranium residues. A wide variety of chemical and metallurgical process steps have been utilized to support the manufacturing of high-purity uranium metal products. Since the curtailment of production

operations in 1989, work at Fernald has focused on the investigation and clean up of the site under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA).

- The **Reactive Metals, Inc. Titanium Company Extrusion Plant** is located on the northern edge of Ashtabula County, slightly east of the city of Ashtabula, Ohio. Beginning in 1962, the primary function of Reactive Metals, Inc. was to extrude slightly enriched, normal and depleted uranium metal for the DOE. The uranium was extruded into rods, tubes and other shapes as an intermediate step in the production of nuclear fuel elements at other DOE sites. The extrusion of uranium for the DOE ceased at the plant in September 1988. During its 26 years of operations, Reactive Metals, Inc. received and shipped recycled uranium mainly with Fernald. Since the cessation of extrusion operations in 1988, the site has been focusing on activities necessary to decommission the site for unrestricted use.

- The **Y-12 National Security Complex**, previously known as the Y-12 Plant, is located at Oak Ridge, Tennessee. The Oak Ridge Reservation was established in 1942 and the site was initially used for electromagnetic isotopic separation to produce enriched uranium for the Manhattan Project. With the development of the gaseous diffusion process in the mid-1940s, Y-12 Complex became an enriched uranium weapons component production facility. Y-12 Complex received and shipped two types of recycled uranium, i.e., highly enriched uranium and depleted uranium. Highly enriched recycled uranium, in the form of uranyl nitrate solution or uranium oxide, was received from the Savannah River Site and the Idaho Chemical Processing Plant, and metal products were shipped to the Savannah River Site. Y-12 Complex received depleted recycled uranium oxide from the Oak Ridge and Paducah GDPs (tower ash) and Hanford; these materials were either shipped back to the gaseous diffusion plants or disposed of at the Oak Ridge Reservation. Y-12 Complex also received highly enriched uranium from the enrichment plants at Oak Ridge and Portsmouth and depleted uranium metal from Fernald for defense applications. Y-12 Complex continues to be a critical part of the Nuclear Weapons Stewardship Program.

- The **Rocky Flats Environmental Technology Site**, previously known as the Rocky Flats Plant, is located between Boulder and Golden, Colorado, northwest of the City of Denver. Rocky Flats processed both depleted uranium and highly enriched uranium materials in fulfilling the DOE mission of fabricating components and assemblies for the U.S. nuclear weapons program. Depleted uranium was processed at Rocky Flats from 1953 through 1993. Depleted uranium metal was received from many suppliers, with about 90% from Fernald and Paducah. Only a small amount of the depleted uranium received from Fernald is considered by Rocky Flats as recycled uranium. Highly enriched uranium was processed at Rocky Flats from 1953 to 1967; however, mass balance data is still classified. Rocky Flats Environmental Technology Site is designated for closure by 2006, with significant activities on going for material stabilization and packaging for long-term storage, building deactivation, and environmental remediation.

As evident from these short summaries and the site reports, the flow of uranium among DOE sites and within various streams at individual sites was extremely complex. Processing sites used recycled uranium to produce materials for reactor fuel and weapons components and shipped the materials to other DOE sites. Since processing normally required multiple steps and production optimization, the sites also interchanged materials among themselves. Operations within DOE frequently and deliberately concentrated the contaminant isotopes, diluted them, and blended them with natural uranium, increasing the total amount of recycled uranium in the complex. This blending caused considerable uncertainty in the data in this study. Also, data on isotope levels are incomplete, and the data between sites is not consistent.

Nonetheless, this review provides a broad understanding of the flow and characteristics of recycled uranium. Collectively, the field site reports describe the flow of recycled uranium from early production through its ultimate uses and disposition. In addition, the site reports identified a number of locations where the isotopes of interest could have concentrated or have been released, including the relevant historical periods, activities and concentrations. This information provides a starting point for identifying personnel exposure or environmental implications. The field site reports also discuss the potential for occupational exposure at these locations, but the methodology used to determine this potential is subjective and does not factor in engineering controls, protective equipment and measures, or results of exposure monitoring.

3.3 Estimated contaminant concentrations in uranium products

Based on process knowledge and laboratory analysis, DOE knows that the contaminants in the various uranium products, e.g., enriched uranium for fuel and weapon fabrication, and depleted uranium for military applications, are extremely low. A brief discussion is given below:

Recycled uranium upon receipt at the GDPs is converted, if necessary, to uranium hexafluoride and fed into the cascades. Plutonium hexafluoride is easily reduced to non-volatile species. Consequently, plutonium entering the cascade was essentially immobilized at the feed points to the cascade. Withdrawals of enriched product and depleted tails are known to include very small quantities of plutonium.

Since neptunium hexafluoride is easy to reduce compared to uranium hexafluoride, neptunium entering the cascade was retained on the high surface area barrier and other process surfaces near the cascade feed points. Very little neptunium ended up in the enriched product or depleted tails.

Technetium formed volatile and semi-volatile chemical compounds that tended to migrate to the top of the cascade with the enriched uranium. Consequently, a larger fraction of the technetium was collected in chemical traps at the top of the cascade. It is reasonable to assume that some technetium ended up in the enriched product because of the evidence of it being deposited throughout the upper cascade. Very little is expected to have migrated toward the lower cascade and into depleted tails.

The summary of the contaminants in the enriched product and in depleted tails for the gaseous diffusion plants is provided in Table 2.

Table 2. Summary of constituents in the enriched uranium product and in depleted tails

Site	Enriched Product	Depleted Tails
Oak Ridge	Pu <0.05 ppb [1] Np <5 ppb [1] Tc <1 ppm [2]	Pu <0.01 ppb [3] Np <5 ppb [3] Tc <10 ppb [3]
Portsmouth	Pu <0.037 ppb [4] Np <3.19 ppb [4] Tc <0.69 ppm [5]	Pu <0.007 ppb [6] Np <0.6 ppb [6] Tc <0.4 ppb [6]
Paducah	Pu <0.01 ppb [7] Np <5 ppb [7] Tc <20 ppm [7]	Pu <0.01 ppb [7] Np <5 ppb [7] Tc <10 ppb [7]

[1] Based on measurement data reported in the R. F. Smith report "Historical Impact of Reactor Tails on the Paducah Cascade", KY/L-1239, Martin Marietta Energy Systems, Inc., Paducah Gaseous Diffusion Plant, March 1984.

[2] Based on data reported in the ETTP report "Recycled Uranium Mass Balance Project, Oak Ridge Gaseous Diffusion Plant, Site Report," June 2000.

[3] Data representing sample analysis of 153 depleted uranium hexafluoride (UF_6) cylinders as reported in the ORNL document "Strategy for Characterizing Transuranics and Technetium Contamination in Depleted UF_6 Cylinders," dated October 2000. For each contaminant, the reported concentrations are near or below the detection limit for these nuclides. This ORNL document also reports upper bound concentrations of dispersed contamination in depleted UF_6 cylinders as follows:

Pu <0.043 ppb
Np < 5.2 ppb
Tc < 15.9 ppb

[4] Based upon three sets of sample data covering the period February 1977 through May 1977 indicating TRU concentrations in very high enriched (VHE) and low enriched uranium product were less than detectable (<5 dpm/g of U).

[5] Based upon sample data reported on February 24, 1977, for Tc concentration in VHE product.

[6] Based upon maximum analytical values from sampling three Portsmouth tails cylinders filled in the 1973 - 1976 period.

[7] Based on data reported in the Paducah report "Recycled Uranium Mass Balance Project, Paducah GDP, Site Report," June 2000.

In the process of converting uranium hexafluoride to metal, contaminant concentration will be further reduced due to differences in solubility of different contaminants in molten uranium. Analyses performed on depleted uranium at the Idaho National Engineering and Environmental Laboratory's Specific Manufacturing Facility resulted in the following maximum, minimum, and average values for five different radionuclides. Table 3 below list values both in terms of pCi per gram of depleted uranium and of grams of material per gram of depleted uranium, presented as ppb. The values given in Table 3 are taken from INEEL/INT-99-01228.

Table 3. Representative sampling of contaminants in depleted uranium at the INEEL

Nuclide	**pCi/g**			**ng/g (ppb)**		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Np-237	3.73	1.14	1.82	5.29	1.62	2.58
Pu-238	2.05	0	0.272	1.20E-4	0	1.59E-5
Pu-239/240	2.66	0	0.406	4.28E-2	0	6.55E-3
Am-241	19.24	0	2.78	5.61E-3	0	8.10E-4
Tc-99	537	64	154	3.16E1	3.78	9.06

4.0 Path Forward

As directed by the previous Deputy Secretary in September 1999, the Department attempted to determine the mass flow of recycled uranium and the mass balance of the contaminants of interest in the recycled uranium in use throughout the DOE complex over the last 50 years. However, due to differences in operational definition of recycled uranium among sites and complexity of uranium processing and

transfer among DOE sites, additional analysis is required to reconcile data related to the production and transfer of recycled uranium.

Inventories and transactions of depleted, normal and enriched uranium have been tracked in the Materials Control and Accountability (MC&A) system using the Nuclear Materials Management and Safeguards System (NMMSS) since 1965. Recycled uranium, however, is a term defined for this study and not currently tracked in the MC&A system. Using NMMSS data, DOE ensures that inventory differences are understood and reconciled for all accountable nuclear materials, including depleted, normal, and enriched uranium.

Additional analysis of definitional differences of recycled uranium and transactions among sites, in the context of the accountable types of uranium, will be conducted to provide a clearer understanding of mass flow of recycled uranium among DOE sites. Specifically, DOE plans to document shipments of all uranium among the field sites and to construct a historical mass balance for uranium, including recycled uranium, for each of the primary recycled uranium sites. For example, Fernald received over 360,000 MTU of uranium over the life the facility; however, only a little over 246,000 MTU was considered potentially recycled. The study is expected to be completed in phases over two years.

Based on the information included in the site reports, the amounts of contaminants of fission products and transuranic constituents in the recycled uranium are extremely low. In addition, DOE believes that it is not possible to develop a "mass balance" of contaminants with available data. With the enactment of the Energy Employees Occupational Illness Compensation Program Act of 2000 and the protocol to be developed by the Department of Labor, it is of no additional value to attempt to develop a "mass balance" for contaminants at this time.

5.0 Conclusions

This overview and supporting field site reports provide a general understanding of the flow and characteristics of recycled uranium including the isotopes of interest—plutonium, neptunium-237, and technetium-99—for the DOE complex over the period 1952–1999. The conclusions are:

- Within the DOE-complex, recycled uranium originated at the four chemical separation sites (Hanford, Savannah River, West Valley, and Idaho). From March 1952 until March 1999, approximately 130,000 MTU was shipped from the four chemical separation sites. Production of recycled uranium was mostly completed by the late 1960s. Most of the recycled uranium went to the six major processing sites.

- Processing operations blended the recycled uranium with natural uranium, which increased the amount of recycled uranium. Taking into account complex-wide inventories and blending operations, it appears that there was more than 250,000 MTU recycled uranium in the DOE complex.

- Based on the site reports for the major processing sites (Paduach, Oak Ridge, and Portsmouth GDPs; Oak Ridge Y-12 Complex; Fernald; and Rocky Flats), the Paducah Gaseous Diffusion Plant appears to have received the largest amounts of recycled uranium, including plutonium as a contaminant.

- The site reports also identified a number of locations where the isotopes of interest could have concentrated or released, including the relevant historical periods, activities and concentrations. These data may be of use for identifying personnel exposure or environmental implications. The field site reports also discuss the potential for occupational exposure at these locations, but the

methodology used to determine this potential is subjective and does not factor in engineering controls, protective equipment and measures, or the results of exposure monitoring.

- The DOE will conduct additional analysis of definitional differences of recycled uranium and transactions among sites, in the context of the accountable types of uranium, to provide a clearer understanding of mass flow of recycled uranium among DOE sites. Specifically, DOE plans to document shipments of all uranium among the field sites and to construct a historical mass balance for uranium, including recycled uranium, for each of the primary recycled uranium sites.

Appendix A. Acronym List

ASTM	American Society for Testing and Materials
AEC	Atomic Energy Commission
CERCLA	Comprehensive Environmental Response, Compensation & Liability Act
CFR	Code of Federal Regulations
DoD	Department of Defense
DOE	Department of Energy
dpm	Disintegrations Per Minute
EH	Office of Environment, Safety, and Health
ES&H	Environment, Safety, and Health
ETTP	East Tennessee Technology Park
FEMP	Fernald Environmental Management Project
GDP	Gaseous Diffusion Plant
g	Gram
HEU	Highly Enriched Uranium
IAEA	International Atomic Energy Agency
ICPP	Idaho Chemical Processing Plant
INEEL	Idaho National Engineering and Environmental Laboratory
MC&A	Material Control & Accountability
MTU	Metric Tons Uranium
ng/g	NanoGram/Gram
NMMSS	Nuclear Materials Management and Safeguards System
Np	Neptunium
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
pCi/g	Picocuries Per/Gram
ppb	Parts Per Billion
ppm	Parts Per Million
Pu	Plutonium
PUREX	Plutonium Uranium Extraction
RMI	Reactive Metals, Incorporated
RU	Recycled Uranium
SMC	Specific Manufacturing Facility
SRS	Savannah River Site
Tc	Technetium
TRU	Transuranic
U	Uranium
U_3O_8	Pitchblende (black oxide)
UF_4	Uranium Tetrafluoride (green salt)
UF_6	Uranium Hexafluoride

UNH	Uranyl Nitrate Solution
UO_2	Uranium Dioxide (brown oxide)
UO_3	Uranium Trioxide (yellow cake)
VHE	Very High Enriched
WVDPA	West Valley Demonstration Project Act

Appendix B. Glossary

"Recycled Uranium" Assumptions - Throughout the world, recycled uranium was mixed or blended with virgin uranium through a variety of processes, such as the enrichment process, to make nuclear reactor fuel or weapons components. Several of these processes dilute or concentrate the transuranic and fission products that are in the recycled uranium. After blending or mixing, the natural uranium and recycled uranium become one product that contains some amount of contamination from the recycled stream. If the product has significant quantities of transuranic and fission products, it would be considered "recycled uranium."

This point of discrimination between recycled uranium and non-recycled uranium has been the subject of technical standards that have been used for over 50 years for radiation safety programs, and ultimately for nuclear licensing and regulation. However, it is also central to the Energy Department's analysis of recycled uranium in order to define the uranium streams to be analyzed.

Atomic Energy Commission - Historical documents indicate that specifications for recycled uranium were set according to the relative amount of radioactivity when compared to the natural uranium and its daughter products, as a percent of alpha, beta, or gamma activity. The values were initially set at a 30 percent increase of the beta activity and a 300 percent increase of the gamma activity. The plutonium specification (or proposed specification) was generally 10 parts of plutonium per billion parts of uranium. A May 2, 1956 document (HW 42975) from the head of Separations Technology Section of Engineering at Hanford indicates that the beta activity value was increased to 100 percent, while the plutonium specification of 10 parts per billion (ppb) remained. Natural uranium at these limits would have approximately a 14% increase in potential inhalation dose. No early limits were specified for neptunium.

U.S. Department of Transportation - The definitions in Title 49, Part 173, of the Code of Federal Regulations (49 CFR 173) contain the statement: "Unirradiated uranium means uranium containing not more than 10^{-6} grams of plutonium per gram of ^{235}U and a fission product activity of not more than 9 MBq (0.24 millicuries) of fission products per gram of ^{235}U." Natural uranium at these limits would present an approximate 9% increase in potential inhalation dose due to plutonium, and an additional approximate 0.2% due to technetium.

International Atomic Energy Agency - IAEA Safety Standards Series, No. ST-1, *Regulations for the Safety Transport of Radioactive Material*, 1996 Edition, defines unirradiated uranium as "Unirradiated uranium shall mean uranium containing not more than 2 KBq plutonium per gram of ^{235}U, not more than 9 MBq fission products per gram of ^{235}U, and not more than 5×10^{-3} gram of ^{236}U per gram of ^{235}U." Natural uranium at these limits would have approximately a 9% increase in potential inhalation dose, due almost entirely to the plutonium and ^{236}U.

U.S. Nuclear Regulatory Commission -10 CFR 20.1204, Determination of Internal Exposure, states, in part, (g) When a mixture of radionuclides in air exists, licensees may disregard certain radionuclides in the mixture if: (1) The licensee uses the total activity of the mixture in demonstrating compliance with the dose limits in 20.1201 and in complying with the monitoring requirements in 20.1502(b); (2) The concentration of any radionuclide disregarded is less than 10% of its derived air concentration; and (3) The sum of these percentages for all of the radionuclides disregarded in the mixture does not exceed 30%.

Under this regulation, licensees were allowed the flexibility in assessing the additional internal exposures of workers to small radionuclide air concentrations provided the total activity of the mixture is still used.

10 CFR 40.13 defines unimportant quantities of source material. Paragraph (c)(5) exempts from this part uranium contained in counterweights installed in aircraft, rockets, projectiles, missiles, or stored or handled in connection with installation or removal of such counterweights, provided that these are labeled as depleted uranium and were manufactured under specific license issued by the NRC or the AEC. Depleted uranium armor for the M1 Abrams Main Battle Tank is supplied by DOE for installation by Army contractors. The NRC licenses for the Army, its vendors and contractors did not contain provisions for trace constituents. These licenses have been amended to include the following paragraph: "Transuranics and technetium-99 contaminants in uranium depleted in uranium-235 will not exceed a total of 100 picocuries/gram of each transuranic and not to exceed 500 picocuries/gram total for all transuranics, . Not to exceed 500 picocuries/gram of technetium-99." It should be noted that a fundamental philosophy in the regulatory context is that impacts less than 10% of the guides, etc. do not have to be accounted for or recorded. However, for depleted uranium simultaneously contaminated at all of the limits would have an increase of approximately 20% in potential inhalation dose.

American Society for Testing and Materials (ASTM) - *Standard Specification for Uranium Hexafluoride for Enrichment*, ASTM Designation C 787-96, defines commercial natural uranium as being distinct from virgin natural uranium. Commercial natural uranium, by this industry standard should contain less than 20,000 ppb uranium-236 and less than 1 ppb technetium-99. The standard states that the uranium-236 limit is a threshold for more detailed isotopic analysis; it does not suggest that the limit is for worker radiological protection. Virgin natural uranium does not contain detectable uranium-236. Commercial natural uranium may be used for enrichment plant feed just as though it was virgin natural uranium. This standard also sets limits for plutonium and neptunium in reprocessed UF_6 (or any mixture of reprocessed and commercial natural uranium) that are equivalent to approximately a 15% increase in potential inhalation dose for a total cylinder, including its heel, or 2% for the volatilized contents.

To assist in the development of sites' preliminary assessments for this study, the Working Group also considered that historical radiation protection programs generally adopted a level of additional dose that warrants additional consideration as +10% of that of the uranium. Constituent levels calculated to produce less than this should not constitute a significantly increased hazard beyond that of the uranium itself, and are considered to be *de minimis* for the purpose of this analysis. The consensus of the group was that sites should assume that "recycled uranium" was generally uranium where trace contaminants contribute approximately 10% above the radiological dose of isotopes in natural uranium.

In an effort to ensure that all uranium streams capable of causing significant transuranic doses were tracked, it was recommended that sites consider uranium forms containing very small concentrations of contaminants if there was a likelihood that further processing would result in concentrating the contaminants to create a uranium byproduct stream that would be considered recycled uranium using this general assumption.